

**REDUCTION OF TORSIONAL OSCILLATIONS IN LARGE  
TURBINE-GENERATOR SET USING THYRISTOR  
CONTROLLED BRAKING RESISTORS (TCBR)**

**Kiran Kumar Karampudi<sup>1</sup>, Harish Cholleti<sup>2</sup>, Ankamma Rao J<sup>3</sup>**

<sup>1</sup>B.Tech. Degree In Electrical & Electronics Engineering From Jawaharlal Nehru Technological University, Kakinada, India

<sup>2</sup>B.Tech. Degree In Electrical & Electronics Engineering From Jawaharlal Nehru Technological University, Hyderabad, India

<sup>3</sup>B.E. Degree In Electrical & Electronics Engineering From Andhra University, Visakhapatnam, A.P, India

**ABSTRACT**

Torsional vibrations and resonance problems with synchronous machines are most frequently encountered in rotor systems with long shafts and large inertias constituting a weakly damped mechanical resonator which exhibits a low resonance frequency. The subsynchronous resonance (SSR) phenomenon may occur when a steam turbine-generator is connected to a long transmission line with series compensation. The main purpose of this paper is to verify the capability of the Thyristor Controlled Braking Resistor (TCBR) to reduce the electromechanical oscillations that occur when a steam turbine generator (T-G) is connected to a long transmission line with series compensation. This investigation was done based on the IEEE Second Benchmark Model. Speed signal is taken as reference to generate pulses to control the TCBR action. By introducing the braking resistor in the network at appropriate times the effect of electromechanical oscillations can be damped out. The Matlab simulink is employed to simulate the effect on stresses of T-G shaft. The simulations results show how the stresses on T-G shaft reduce with the application of TCBR.

**Keywords:** Capacitor compensated transmission lines, power generation mechanical factors, power system dynamic stability, power system modelling, subsynchronous resonance, thyristor applications, turbo-generators, Thyristor Controlled Braking Resistors

## **I. INTRODUCTION**

Series compensation of power transmission line is an important way to improve power transfer capability, to control load sharing among parallel lines and to enhance steady state stability of a long transmission lines. However, series compensation in transmission networks leads to SSR phenomenon [1]. It means that the interaction of complimentary frequency of the system( the difference of system frequency and system's natural frequency) with the natural frequencies of turbine masses leading to mechanical torque amplification which results in shaft failure [2], [3]. The phenomenon of SSR on alternating current power system was first treated in technical literature in 1937. SSR phenomenon was first observed and resulted in destruction of two generator shafts at Mohave Power Station on December 9, 1970 and again on October 26, 1971 in USA [4]. After failure of shaft at Mohave Power Station it was found that SSR is an interaction between mechanical system and electrical network.

The torsional oscillations due to SSR cover a wide frequency range approximately from 0.001 Hz to 50 MHz. Due to transient perturbation, the generator accelerates and its rotor angle increases causing the development of varying torque. This varying torque develops the varying stresses on the T-G shaft, which leads to damage of the shaft and may reduce life of T-G set. There are many techniques to damp out these torsional oscillations using FACTS devices can be found in literature.

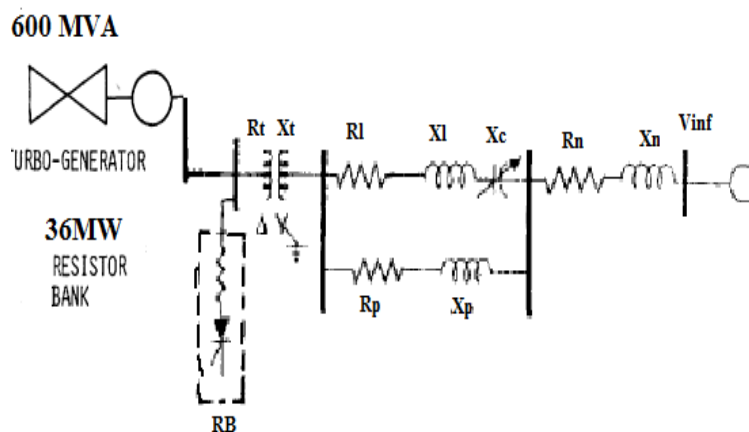
In general, the advantages of series compensation can be achieved without developing SSR which can be guaranteed using FACTS devices. Many techniques to mitigate SSR with series FACTS devices have been presented by researchers in the literature. These techniques achieve successful series compensation and reduce or even eliminate the effects of the subsynchronous resonance [5]. There have been many works carried out on FACTS devices in mitigating SSR phenomenon. Hingorani [6] proposed a very effective device for SSR mitigation called NGH-SSR Pilotto. [7] have shown that TCSC using local current or power control can efficiently eliminates the SSR problem.

The Thyristor Controlled Braking Resistor (TCBR) is a shunt-connected thyristor-switched resistor (usually a linear resistor) which is controlled on or off, half-cycle by half-cycle to aid stabilization of power system transients and subsynchronous oscillations by reducing the net available energy for acceleration and hence speed deviation of the generating unit during a disturbance. TCBR is also called as a Dynamic Brake. TCBR can be utilized for variety of functions like preventing transient instability during first power system swing cycle, enhance damping to prevent dynamic instability involving low frequency oscillations between interconnected ac systems. There have been many research contributions made in past times in designing and developing effective TCBR control schemes to mitigate the torsional oscillations. The first development of dynamic resistors was performed by B.C. Hydro [8]. An 1400 MW dynamic braking resistor was applied to a temporarily surplus electric power pool at the Northwest power pool and the Southwest power pool of the WSCC council [9]. The control scheme suggested by O. Wasynczuk in was worth noting, in which, a small dynamic braking resistor of about 6% of the generator rating is employed. R.M Hamouda gave another effective firing angle control scheme for the braking resistor control.

In this study, a method of damping shaft torsional oscillations using a dynamically controlled three phase resistor bank is examined. Previously. There have been many works made on for augmenting system stability as well as for improving the transient response of power systems following major system disturbances and their application in damping shaft torsional oscillations has also been explored. This paper describes another method that can be used to control the power consumed by a resistor bank for the purpose of damping the torsional modes of turbogenerators. A study system is defined and the shaft torques following various system disturbances are analyzed. It

is shown that the use of a resistor bank can efficiently damp out the electromechanical oscillations and retain the system stability.

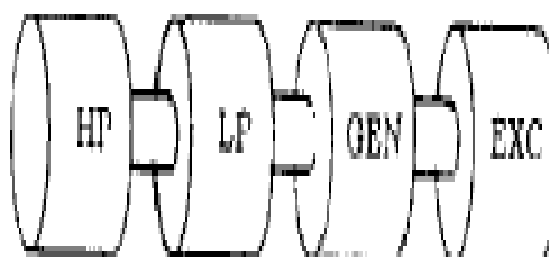
## II. SYSTEM MODELING



**FIG. 1. IEEE SECOND BENCHMARK MODEL FOR SSR DAMPING STUDIES**

The one line diagram of the IEEE Second Benchmark Models shown in [10] Fig.1. A 600 MVA generator is being connected to a 500KV parallel transmission line through a 600MVA transformer. A bolted three phase fault is created on one of the line. The transmission line is represented by the sending end transformer reactance  $X_T$ , the line resistance  $R_L$ , the transmission line reactance  $X_L$ , the equivalent system reactance  $X_S$ , of infinite bus and the reactance of series compensation  $X_{fc}$  on one of the line.

The mechanical system comprises four masses, i.e. the high pressure turbine (HP), the low pressure turbine (LP), the generator (GEN), & the exciter (EXC) as shown in Fig. 2. Mechanical damping is considered for all masses. The generator is equipped with a static excitation system.



**FIG. 2. FOUR MASS ROTOR MODEL OF T-G SET**

From the structure of this mass spring system, there exist two torsional modes (mode-1, mode-2) and one electromechanical mode (mode-0) in the system. These three modes are called SSR modes or torsional modes since their natural frequencies are all less than synchronous frequency or power frequency. The inherent natural frequencies for mode 0, 1, 2, 3 and 4 are 0.0Hz, 15.7Hz, 28.3 Hz, 32.5Hz and 47.45Hz respectively. SSR modes stand for number of twists on the shaft. For example mode 0 signifies that the all masses oscillate in unison without a shaft twist, mode-1 has one shaft twist and mode-2 has two shaft twists and so on.

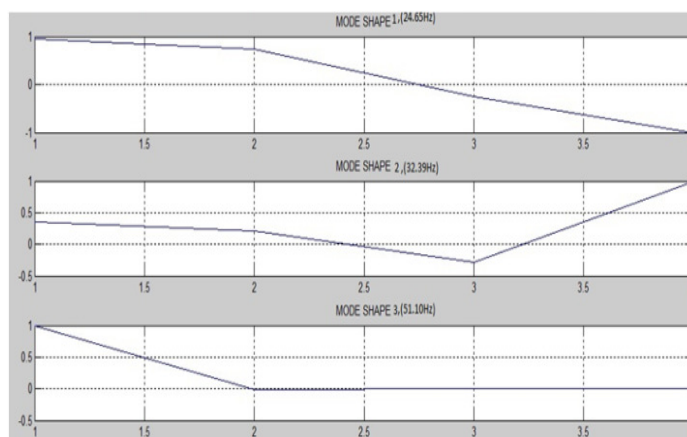
### III. SYSTEM PARAMETERS

The system under study comprises of a generator of rating 600 MVA connected to a transmission line of capacity 500 KV through a transformer of per unit reactance 0.02. The base impedance of the system is equal to 2.5k $\Omega$ . The mechanical system consists of a two-stage steam turbine, the generator, and a rotating exciter.

Table I shows the torsional modes of oscillations and electromechanical mode of this system with the corresponding oscillating frequencies.

**Table I. MODE FREQUENCIES THAT EXCITE SSR**

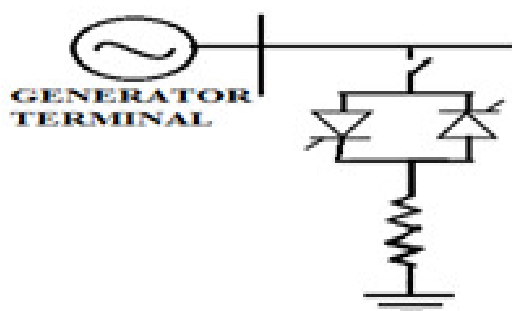
Mode	Frequency
Torsional 3	51.1 Hz
Torsional 2	32.39 Hz
Torsional 1	24.65 Hz



**Fig. 3.** Mode graphs corresponding to mode 1, mode 2 & 3

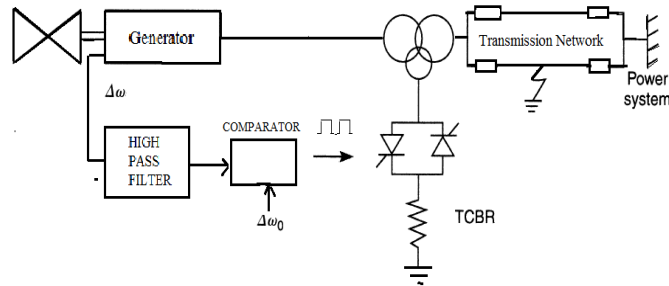
### IV. THE THYRISTOR CONTROLLED BRAKING RESISTOR (TCBR)

The TCBR is composed of two anti-parallel gate-controlled switches and a braking resistor in parallel at the terminals of the generator as shown by the single line diagram in Fig. 3.



**Fig 4.** Basic circuit representation of the TCBR

In order to switch on the resistor bank when the torsional components of the generator speed signal step out a preset level, it is necessary to isolate these higher frequency components. This can be accomplished by filtering the generator speed signal using a high pass filter which passes the torsional frequencies of the prime mover and attenuates Lower frequencies. The filtered generator speed can then be used to control the power dissipated by the resistor bank as in Fig. 5 thus producing a torque which opposes only the components of the generator speed associated with the torsional modes.



**Fig. 5.** Control scheme of a TCBR

#### A. Mathematical Analysis

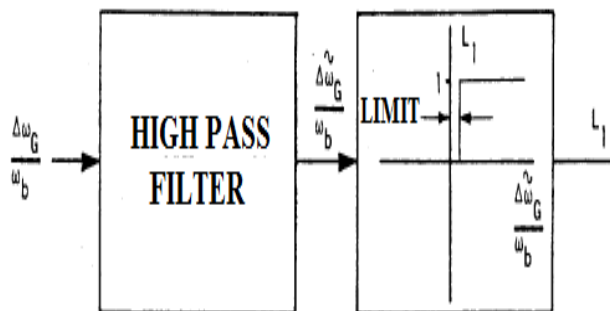
The amount of power dissipated in a thyristor can be given as,

$$P_{TCBR} = \frac{1}{\pi} \int_0^{\pi} V_{iR} d(\omega t) = \frac{V_g^2 G_{TCBR}}{\pi} (\pi - \alpha + 0.5 \sin 2\alpha)$$

Following a fault, current flows through BR if thyristor T1 or T2 is in ON state, and it decreases the accelerated power by consuming excessive transient energy. In this way, during large disturbances, the braking resistor can control the speed deviation and accelerating power in generators, and thereby makes the power system stable by bringing speed deviation and accelerating power near the equilibrium point. Firing angle ( $\alpha$ ) for the thyristor switch is calculated from the output of the PI controller (i.e.,  $G_{out}$ ). The desired power consumption determined by  $G_{out}$  and the real power consumption determined by  $G_{TCBR}$  are equal and hence firing-angle,  $\alpha$ , can be calculated from the following power equation.

$$P_{TCBR} = P_{out} \frac{V_g^2 G_{TCBR}}{\pi} (\pi - \alpha + 0.5 \sin 2\alpha) = V_g^2 G_{out}$$

#### B. Control Methodology



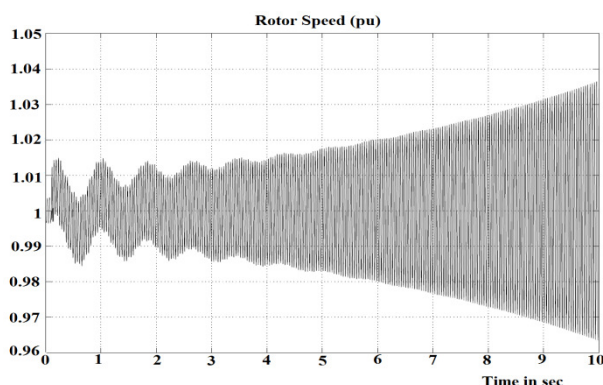
**Fig. 6.** Simplified control circuit to generate pulses

Fig. 6 shows the simplified control circuit to generate the pulses for controlling the power dissipated in the braking resistor. As stated before, whenever the torsional components of the generator speed signal exceed a preset level, the braking resistor is activated such a way that the some portion of generator power is bypassed into the resistor bank so that the stability margin, conversely increasing the stability limit. To achieve this we need to filter the generator speed signal using a filter. The speed signal so obtained is normalized as shown in Fig 6. Here L1 is the gating signal which is 0 when the torsional components are within limit and, is 1 for the other case.. The deadband prevents the resistor bank from being activated during small changes in generator speed.

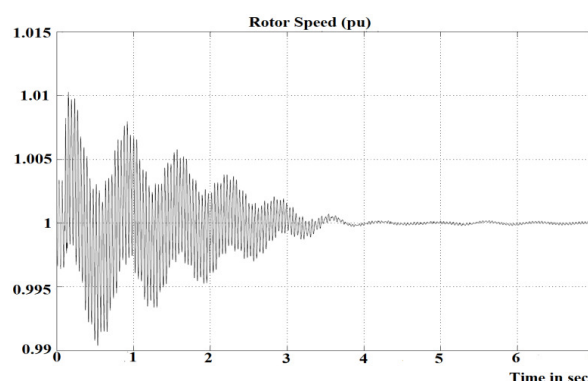
## V. SIMULATION RESULTS

The torsional modes of the system have its largest SSR interaction at a certain value of the series compensation  $X_{fc}$ . Without TCBR, various torsional frequencies vary in magnitude and become unstable at different levels of series compensation.

The single line diagram as shown in Fig. 1 is modeled by using Matlab-Simulink. To support the results of the torsional oscillations, time domain simulation based on nonlinear differential equations of the system, under a three phase fault at the infinite bus, is performed. All system nonlinearities are included in the model. The three-phase fault is initiated for fault duration 0.1 sec. The generator speed signal is considered as reference to generator ON pulses for the thyristors of the TCBR. The TCBR is assumed to consume 6% of the generator power. The simulation results of dynamic responses without and with TCBR are compared and analyzed.

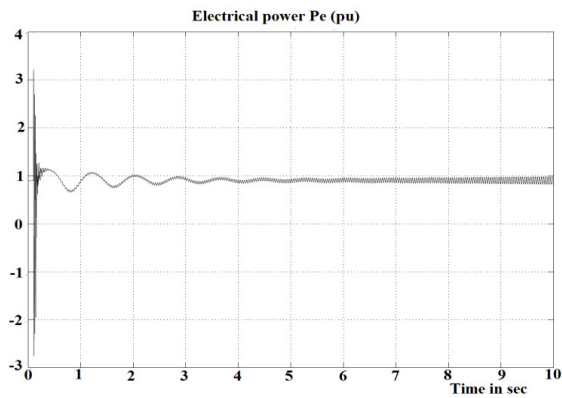


**Fig 7.** Variation of rotor speed without TCBR

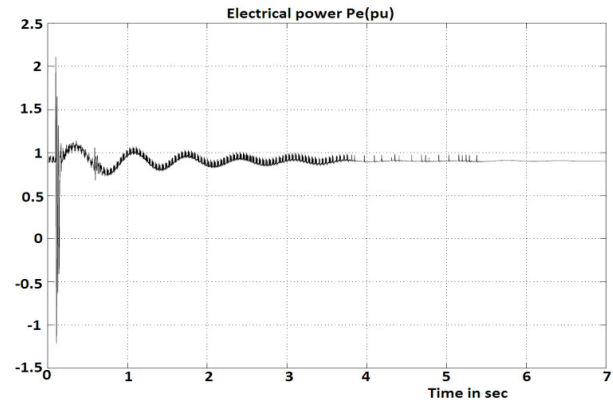


**Fig 8.** Variation of rotor speed with TCBR

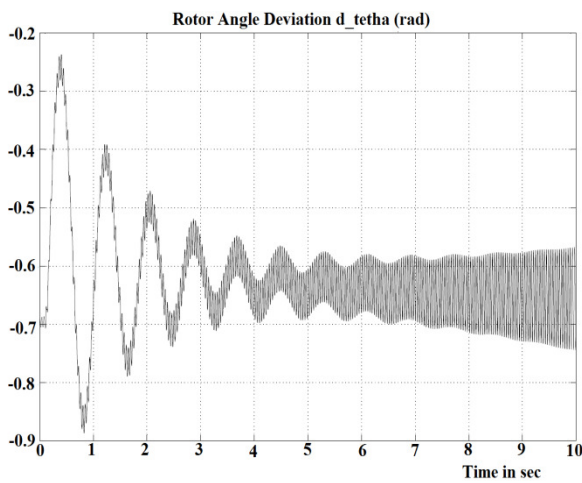
The variation of generator electric power without TCBR is shown in Fig. 9. The variation of generator electric power with TCBR is shown in Fig. 10. The variation of stresses at the coupling with and without TCBR is shown in the below figures.



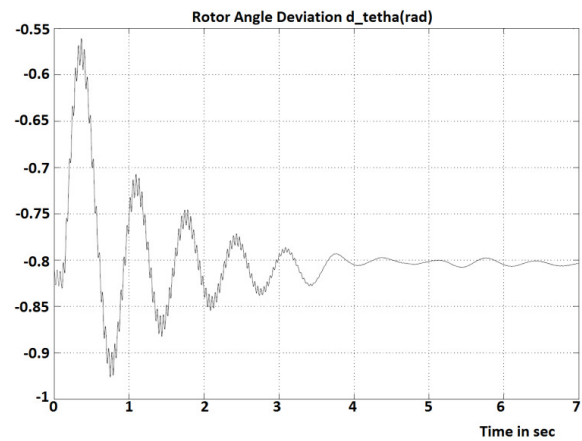
**Fig 9.** Variation of electric power without TCBR



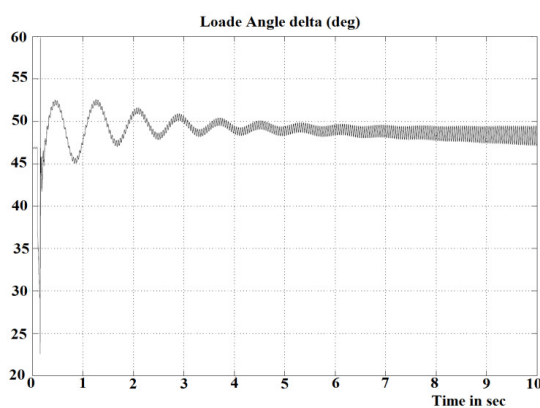
**Fig 10.** Variation of electric power with TCBR



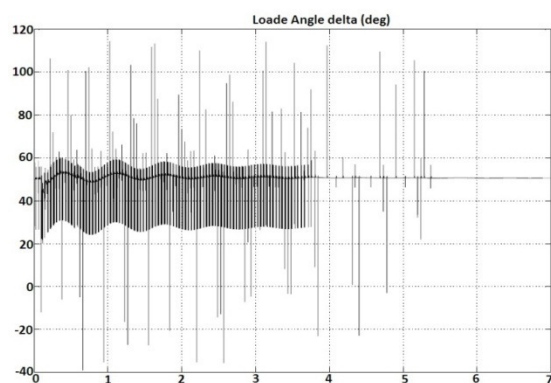
**Fig 11.** Rotor angle deviation without TCBR



**Fig 12.** Rotor angle deviation with TCBR



**Fig 13.** Load angle without TCBR



**Fig 14.** Load angle with TCBR

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## **AUTHORS BIOGRAPHY**



Mr. Kiran Kumar Karampudi received the B.Tech. degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Kakinada, India, 2009 & M.Tech. degree in in Power Electronics and drives from Visvesvaraya National Institute of Technology, Nagpur, in 2012. He Worked as Assistant Professor in Avanthi College of Engineering and Technology, Hyderabad, India. His research areas are power system Analysis and FACTS.



Mr. Harish Cholleti received the B.Tech. degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, 2009 & M.Tech. degree in in Power Electronics and drives from Visvesvaraya National Institute of Technology, Nagpur, in 2012. He Working as as Assistant Professor in CBIT Engineering college, Hyderabad, India. His research areas are Power Electronics and FACTS



Mr. J Ankamma Rao received the B.E. degree in Electrical & Electronics Engineering from Andhra University, Visakhapatnam, A.P, India, 2007 & M.Tech. Degree in Integrated Power System from Visvesvaraya National Institute of Technology, Nagpur, India, in 2012. Currently, he is an Assistant Professor in Samara University, Samara, Afar Region, Ethiopia. His research areas are power system protection and FACTS.